A W-band HEMT based power amplifier module for millimeter-wave LO multipliers

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ABSTRACT

We report on the performance of power amplifiers as local oscillator drivers for millimeter and submillimeter-wave receivers. A MMIC power amplifier based on 0.1 micron GaAs HEMT technology on 50 micron thick substrate has been packaged in a waveguide block and characterized. Output power in excess of 100 mW is demonstrated over 88-94 GHz with more power easily achievable. The noise properties of the MMIC amplifier in multiplied local oscillator chains are characterized in a low noise superconductor-insulator-superconductor mixer based heterodyne receiver. A 386 GHz SIS mixer was used to characterize noise temperature in a laboratory environment. A more sensitive measurement of noise contribution from the amplifier was performed on a 278 GHz mixer/receiver at the Caltech Submillimeter-Wave Observatory, during astronomical observations. It is concluded that the MMIC amplifier does not add additional significant noise to the radiometer system.

Keywords: power amplifiers, local oscillators, radiometers, LO noise

1. INTRODUCTION

A critical component of all heterodyne receiver systems is the local oscillator (LO) source that enables the mixing device to produce the IF signal. Traditionally, in submillimeter-wave receivers a Gunn diode oscillator followed by the appropriate frequency multiplier has been used to provide the LO source. While this combination has worked well and technology development of Gunn devices [1], multiplier devices[2], and multiplier circuits[3] continues to improve LO sources, there are compelling reasons to look beyond Gunn oscillators as the fundamental source of power in the LO chain. One inherent limitation of Gunn diode circuits and transit-time device circuits is the very limited electronic tuning bandwidth that can be achieved. For space-borne applications, it is desirable to have all frequency tuning performed electronically, without the potential of mechanical failure. There has been some effort in extending voltage tuning bandwidth of Gunn devices at W-band, but this has resulted in severely degrading the output power. Voltage controlled W-band Gunn oscillators with 10% bandwidth have been demonstrated, with output power degraded to 10 mW [4]. Moreover, each Gunn diode oscillator circuit requires individual tuning making it difficult to produce them in large quantities.

Recent advances in the upper frequency limit and output power of three terminal devices has now made it possible to consider them as an alternative to fundamental oscillator sources [5,6,7]. 50 micron thick substrate, 0.1 micron GaAs high electron mobility transistor (HEMT) technology has now yielded state-of-the-art MMIC power amplifiers at W-band that have put out 0.25W peak output power [7]. Use of this technology as the highest frequency power generation source in a LO chain, raises questions about the noise contributions of the amplifier to the receiver. We examine the noise properties of low noise receivers pumped by a W-band MMIC power amplifier.

2. TECHNOLOGY

The MMIC power amplifier (PA) is a two stage monolithic W-band chip using 0.1-um pseudomorphic AlGaAs/InGaAs/GaAs T-gate power high electron mobility transistor (HEMT) process. The substrate of the chip has been thinned down to 50 microns. A photograph of the amplifier chip is shown in Figure 1.

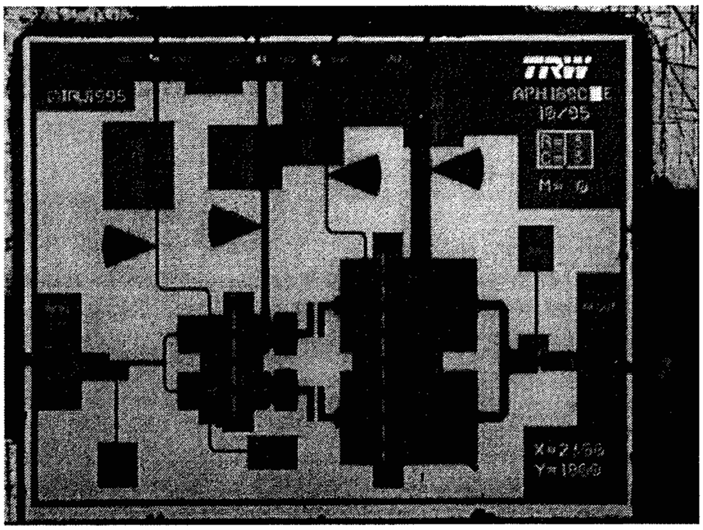


Figure 1: Photograph of the W-band monolithic power amplifier.

The chip, 2300x1800 μm^2 in size, has been packaged in a split-waveguide block housing, based upon a University of Massachusetts [8] design. E-plane probes are used for input and output coupling between the waveguide and microstrip. Simple wire-bonds are used to connect the probes, which are fabricated on 75 μm thick Teflon, to the chip. Appropriate bypass capacitors are used to enable biasing of the chip without oscillations. Figure 2 shows the lower half of the split block with the MMIC chip in place.

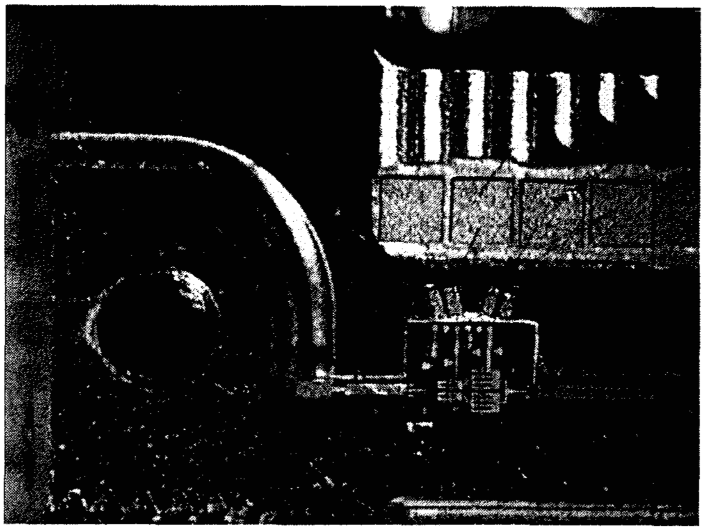


Figure 2: Photograph of the PA inside the lower half of the waveguide block.

It should be pointed out that the MMIC had to be mounted so that there was a relatively long microstrip line on the output of the amplifier given the available fixture. We estimate this to cause 2-3 dB of extra loss on the output which will be corrected in the blocks that are being fabricated and assembled.

The measured available small signal gain of the packaged PA is shown in Figure 3 and was approximately 10 dB from 90 to 95 GHz. The drains were biased at 3 volts with 280 mA of current while the gate voltages were held at 0 V for this particular measurement. The measurement was performed on a Hewlett-Packard 8510 vector network analyzer with custom millimeter-wave heads fabricated by Oleson Microwave labs.

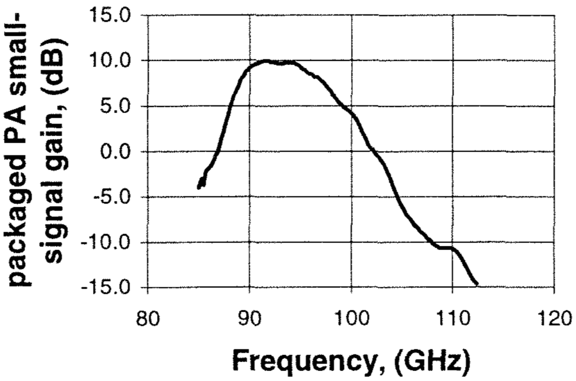


Figure 3: Measured small signal gain of the PA. Drain bias for both stages was 3 Volts at 280 mA total current. The gate voltage was 0 V.

A 75-110 GHz Backward Wave Oscillator (BWO) tube was used to provide an input signal to measure the frequency response of the PA under large signal conditions. The BWO was used because of the easy availability, wide bandwidth and high output power. However, for space borne applications a commercially available YIG based active multiplier will be used. The output power was measured with an Anritsu power meter and is shown in Figure 4.

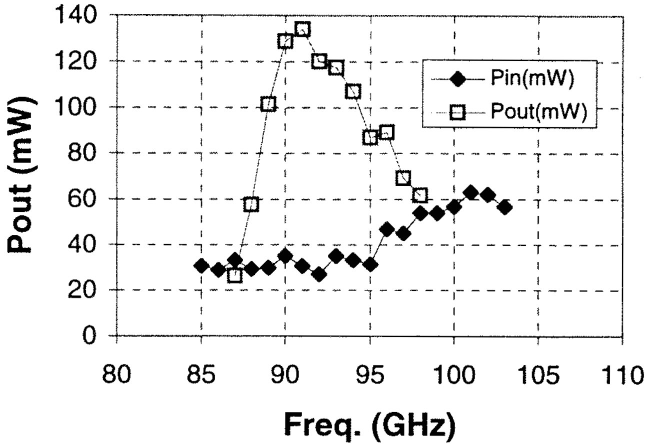


Figure 4: Measured output power of the PA as a function of frequency. The input power measured on a coupler is also shown corrected for the coupling value .

3. NOISE CHARACTERISTICS

For low noise millimeter and submillimeter-wave radiometers, the noise added by the LO can cause serious degradation in the receiver sensitivity. Both AM and FM noise can be added by the LO source into the IF signal. If the LO signal has noise sidebands at the RF frequency, that noise is down- converted to the IF frequency increasing the noise temperature of the receiver.

The noise of HEMT transistors has been characterized as an input Johnson noise from input resistors at the quiescent operating temperature, and an output Johnson noise due to the drain-source resistance at an effective temperature proportional to the drain-source current density [9]. For the PA in the LO chain, both amplified input and output noises contribute to the total source noise. Typical values for the equivalent thermal noise at the output of the W-band PA could be higher than 5000 K. Propagation of this noise through the multiplication chain is difficult to calculate. A comparison of this noise relative to the noise of the high-Q cavity stabilized Gunn oscillator could be a critical design issue for low-noise receiver systems.

In addition to the thermal noise component, HEMT devices are well known to exhibit 1/f noise in the device transconductance. While unlikely, this noise can extend to high enough frequency to enter the receiver IF band (1-2 GHz or higher), fluctuations in the LO power could reduce the sensitivity of the receiver in an observing situation. The purpose of our initial investigation is to understand the noise properties of the MMIC PA applied to sensitive heterodyne receivers. Two experiments have been carried out.

In the initial experiment, a laboratory version of a superconductor-insulator-superconductor (SIS) mixer operating at 386 GHz was used. The mixer nominally utilizes a free running Gunn diode at 96.7 GHz followed by a Schottky diode quadrupler. The mixer noise temperature was measured with two different LO configurations as shown in Figure 5.

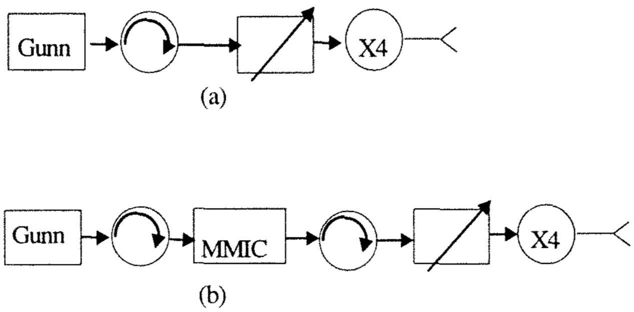
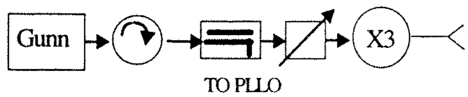


Figure 5: LO chain configuration (a) with the Gunn diode oscillator, (b) with the MMIC PA inserted into the LO chain.

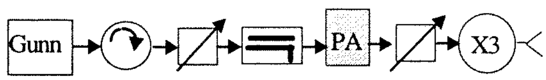
In both cases, the pumped current through the SIS junction was monitored and kept constant. In configuration (A), the standard operating mode, a receiver noise temperature of 219-222 K was measured. In configuration (B), inserting the PA with level setting attenuators and isolators between the Gunn oscillator and multipliers, a noise temperature of 217-214 K was measured. Additionally, in a third configuration, a waveguide bandpass filter (92-96 GHz) was added between the MMIC amplifier and the second isolator for the purposes of limiting the amplifier noise available to the RF passband. This resulted in a possible marginal reduction in the noise temperature, measured to be 208-210 K. In either case, the application of a driver amplifier does not significantly degrade the noise temperature of the SIS receiver.

In order to get a better estimate of the noise contribution from the amplifier in the LO chain, the experiment was repeated in an observing session on a more sensitive receiver with a phase-locked Gunn at the Caltech Submillimeter Observatory (CSO) at Mauna Kea, Hawaii. This also provided the opportunity to test whether an amplifier in the LO chain reduces the receiver sensitivity during astronomical observations.

A 278 GHz SIS receiver on the CSO was used to observe the Methanol (CH_3OH) line in the Orion-South Nebula. The initial LO chain configuration is shown in Figure 6 (a). The Gunn is phase locked and a receiver noise temperature of 22.5 K (double side band) was measured using hot and cold loads. The observation was done with an integration time of 400 seconds and a number of scans were done for accuracy. The telescope was then pointed to a dark sky target to measure the noise floor. The MMIC amplifier was then inserted into the LO chain as shown in Figure 6 (b). The measured noise temperature of the receiver was 21.3 K double side band while keeping the SIS current identical to the measurement with the Gunn diode. The same observation of the Orion Nebula with identical integration time and scans was carried out. Figure 7 shows the measurement of the Methanol line, both with the Gunn diode and the MMIC PA. As can be seen there is no discernible line broadening and the noise floor in both cases is the same. Figure 8 shows the noise floor fluctuations from the two different LO configurations, again indicating no major discrepancy. This leads one to believe that the PA is not adding any extra noise into the radiometer.



(a)



(b)

Figure 6: LO chain configuration at the CSO with and without the PA. A second isolator between the PA and the multiplier would have been desirable but we were physically unable to fit one in given the mounting mechanics on the base plate.

4. CONCLUSION

Sensitive heterodyne receivers are used to investigate the noise properties of HEMT based power amplifiers as drivers for a LO chain. A broad-band W-band amplifier was packaged in a waveguide block demonstrating more than 100 mW of power from 88-94 GHz. This amplifier was then tested both in the lab and at the CSO to pump SIS mixers at 386 and 278 GHz respectively. Based on the measured receiver noise temperatures and the amplitude and shape of the measured signal from the Orion Nebula it is concluded that the MMIC PA does not add any significant additional noise to the receiver.

5. ACKNOWLEDGMENTS

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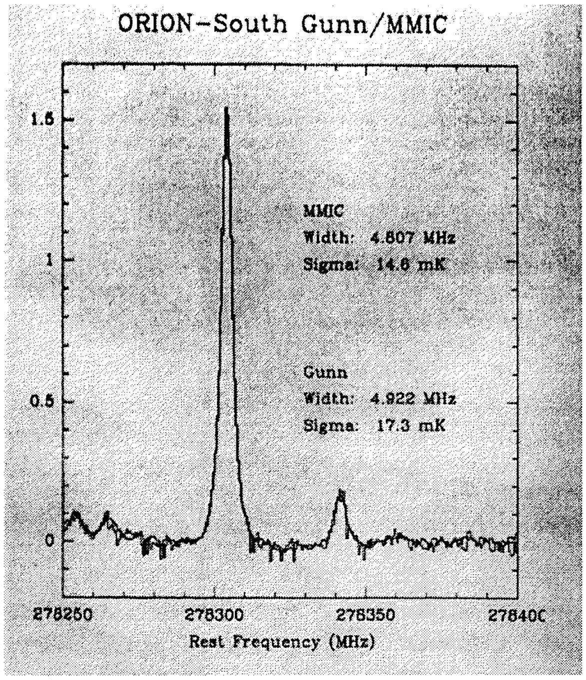

Figure 7: Observation of the Methanol line in the Orion Nebula with the two different LO chains as shown in Figure 6. Addition of the PA does not deteriorate the observation.

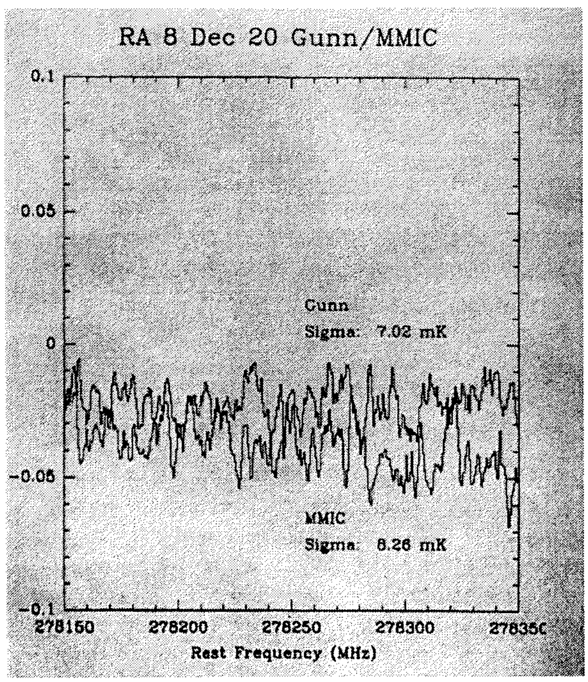

Figure 8: The above signals are obtained when the telescope is pointed to a dark sky target.

6. REFERENCES

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